(4)

AD-A206 452

REPORT DOCUMENTATION PAGE

DTIC FILE COPY

1b. RESTRICTIVE MARKINGS

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release: distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
Technical Report #89-2.

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Washington University

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION
Office of Naval Research (CODE 1142PT)
Personnel & Training Research Programs

6c. ADDRESS (City, State, and ZIP Code)
660 S. Euclid, Box 8111
Dept. of Neurology & Neurological Surgery
St. Louis, MO 63110

7b. ADDRESS (City, State, and ZIP Code)
800 North Quincy Street
Arlington, VA 22217

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
N00014-86K-0289

8c. ADDRESS (City, State, and ZIP Code)

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO
61153N	RR04206	RR04206-OA	NR442a554

11. TITLE (Include Security Classification)
Relating Attention to Visual Mechanisms

12. PERSONAL AUTHOR(S)
Gordon L. Shulman

13a. TYPE OF REPORT
Technical

13b. TIME COVERED
FROM 7/1/88 TO 6/30/89

14. DATE OF REPORT (Year, Month, Day)
February 28, 1989

15. PAGE COUNT
19

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
05	10	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

DTIC
S ELECTE D
MAR 1 7 1989
H

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
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22c. OFFICE SYMBOL
ONR 1142PT

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

(Submitted to Perception & Psychophysics, 1989)

Relating Attention to Visual Mechanisms

ONR Technical Report #89-2

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The effect of attention on visual perception has been a subject of great controversy. Much research on attention over the last thirty years has been framed by the debate on this question between proponents of early and late selection.

Late selection theorists ~~(Deutsch & Deutsch, 1964; Keele, 1973; Duncan, 1980)~~ have argued that all perceptual encoding, including recognition, and certain semantic analyses are accomplished in parallel, while early selection theorists ~~(Broadbent, 1982)~~ have countered that only simple 'physical' analyses can be conducted in parallel. More sophisticated analyses of shape that support object recognition and memory access are conducted by limited capacity systems.

Although the terms 'perceptual' and 'semantic' include a wide variety of processes, there has been an unfortunate tendency to extrapolate conclusions to the entire collection of processes based on results from a few. For example, researchers have tacitly assumed that if any evidence for semantic processing of unattended material is found, then perceptual operations must be parallel. This inference, however, only applies to the perceptual operations relevant to the recognition of the experimental stimuli, which are generally upright block alphanumeric characters. Recognition of these stimuli does not require the resolution of a vast number of problems the visual system must solve: the analysis of motion, three-dimensional space, constancies of various sorts, etc.

More direct evidence that perceptual operations are parallel has been collected using visual search tasks, (Neisser, 1963; Egeth, Jonides & Wall, 1972) in which the experimenter measures the reaction time to decide whether a prespecified target appears in an array. If reaction time is independent of array size, then the operations underlying search are considered parallel; if reaction time increases with array size in a linear fashion, then the underlying operations are assumed to be serial (or parallel but capacity limited (Townsend, 1972)). Visual search studies over the last several decades have detailed the conditions over which search is parallel or serial. Since early studies indicated that search was particularly efficient when targets were defined by gross physical differences (Neisser, 1963), researchers during the 1970's attempted to demonstrate that parallel search could be based on memory dependent qualities such as category (Egeth, Jonides & Wall, 1972; Shiffrin & Schneider, 1977; Schneider & Fisk, 1984; Duncan, 1984). In the 1980's, Treisman and colleagues (Treisman & Gelade, 1980; Treisman & Souther, 1985; Treisman & Gormican, 1988) attempted to define more carefully the 'physical' features that produced parallel search. They concluded that single features could be analyzed in parallel but that conjunctions of features required attention.

Results demonstrating parallel search for single features should not be overgeneralized. Early studies focused mainly on search defined by form or color. While recent studies have expanded the list of attributes under consideration (Nakayama & Silverman, 1986; Wolfe & Franzel, 1988), a large number of visual processes have still not been considered.

Most visual search studies yielding parallel functions have also involved fairly crude discriminations, such as 'S' from 'T' and 'X', or blue from brown and green (Treisman & Gelade, 1980). More difficult discriminations generally yield serial functions (Gardner, 1973; Bundesen & Pedersen, 1983; Treisman & Gormican, 1988). Although visual search techniques have not been applied to most of the threshold tasks studied by psychophysicists (vernier acuity, stereoacuity, wavelength discrimination, etc.), one would expect them to also show serial functions when threshold stimuli are used as targets. Given the usual interpretation of visual search functions, one might conclude that most mechanisms underlying early vision are capacity limited. However, there are difficulties in the interpretation of serial search functions.

Since the development of visual search techniques in the 1960s and 1970s (Neisser, 1963; Egeth, Jonides & Wall, 1972) it has been widely appreciated that the logic relating display size effects to attentional limitations is flawed (Eriksen & Spencer, 1969; Shiffrin & Gardner, 1972). As one increases display size, one also increases the probability of noise generated false alarms. It is for this reason that the visual search technique has not been applied to the study of thresholds and fine discriminations so widely studied in psychophysics, producing an unfortunate gulf between the cognitive and psychophysical literature. (The basic problem still remains even with the crude discriminations studied in visual search tasks, prompting the development of methods that do not share this problem (Eriksen & Spencer, 1969; Shiffrin & Gardner, 1972; Duncan, 1980)).

In a modification of the above analysis Treisman & Gormican have proposed that attention determines the spatial region over which evidence for the presence of a feature is pooled. With gross discriminations pooling can occur over a wide area since distractors and targets are sufficiently separate that distractor noise will not activate target detectors. However, with fine discriminations, noise can more easily activate target detectors. To prevent false alarms, evidence from restricted regions must be considered serially.

Other explanations of the serial functions found under conditions involving fine discriminations are possible. Perhaps, for example, the grain or resolution of the representation that is computed is affected by attention. Additionally, it is misleading to talk about a single representation since most perceptual properties are derived through a complex series of computations. Consider motion perception. Some models posit an initial filtering stage in which the input is analyzed by orientation, direction, and spatial frequency specific mechanisms, followed by an integration stage in which motion along different contours is integrated to yield an 'object' motion (Movshon, Adelson, Gizzi, & Newsome, 1985). Eye movements also need to be taken into account as well as motion of surrounding objects and context (Johannson, 1975). The point is that the extraction of any perceptual property requires a series of operations that are not separated in the standard visual search task. The serial function found with difficult discriminations could be imposed at a variety of computations. Finally, the difficulty may lie in the fact that subjects are required to make a direct report about the presence or absence of a target. As a number of researchers have pointed out, direct reports require a series of processes from image encoding through response selection (Allport, 1977; Duncan, 1980). Effects of attention can occur at any point in this sequence. In a visual search task, the target stimulus must first be analyzed and then passed from parallel to limited capacity systems for decision and response. That is, for pop-out to occur, an identified target must generate an attention-summoning signal so that information from that location can be passed by selection mechanisms to response related stages. The performance increases caused by consistent mapping training (Shiffrin & Schneider, 1977), for example, may be due to the attachment of this interrupt signal to particular stimulus representations rather than the initial analysis of the stimulus. The limitation implied by a serial function may therefore be imposed at the stage at which information is transferred to decision and response processes.

In summary, visual search studies do not force the conclusion that perceptual operations are automatic. Visual search techniques have been applied to a limited range of perceptual operations, and within this range serial functions are found if the discrimination is made difficult. These serial functions have multiple interpretations; the limitations they reflect could arise from a variety of mechanisms.

The problem of specifying the process on which attention acts is also apparent in other recent studies of the effect of attention on perception. For example, cueing has been shown to aid various types of feature detection (Prinzmetal, Posner & Presti, 1986; Downing, 1988). The difficulty again is that standard cueing tasks do not distinguish different levels of perceptual representations and require direct reports. To the extent that a stimulus is more efficiently transferred - faster and/or with less noise added - when it is spatially attended, one will find beneficial effects of spatial cueing in virtually all tasks requiring direct report. An effect of cueing on vernier acuity, for example, would not imply that attention affects early visual mechanisms.[2]

One solution to this problem might involve making better use of the techniques developed by perception researchers to isolate perceptual processes for careful study. For example, a general strategy in perception has been to study various misperceptions or illusions that reflect the application, misapplication, or absence of specific computational routines. By embedding attentional manipulations within these paradigms, it may be possible to localize the effects of attention to particular computations.

Gogel and Tietz (1976) asked observers to judge the direction of motion of a single dot moving up and down that could be steroscopically presented at either a far or near distance (figure 1). Two pairs of horizontally moving 'context' dots were also displayed, one pair on a TV screen placed at the near distance, one at a second TV screen at the far distance. Each pair consisted of one dot whose vertical position corresponded to the 'top' of the test motion, and one corresponding to the 'bottom'. The pair moved horizontally in a coupled fashion as the test dot moved vertically between them. However, the relative phase of the near and far pair was reversed (one pair moved left while the other was moving right and vice versa). As a result, if each pair had been presented in isolation, the test dot would have been perceived to move obliquely in different directions. Gogel and Tietz determined the effect of a particular context pair by measuring the perceived direction of the test dot as a function of its depth separation from the pair and whether the pair was attended. Attention was manipulated through instruction. Subjects were told to attend to one pair and ignore the other. Gogel and Tietz found that a given context pair was more effective in producing the appropriate tilted motion path for the test dot if that pair was attended.

In a second study, Gogel and McCracken (1979) presented a vertically moving test dot at different depths with respect to a single horizontally moving context pair. Subjects were told to judge the direction of motion of the test dot and either attend or ignore the context dots. Gogel and McCracken again found a greater effect of the context pair on test dot direction (i.e. it was seen as more oblique) when it was attended.

The main question in these studies is not whether attention improves the accuracy of report (the dot is actually moving vertically) but how it affects an aspect of that report that can be related to a particular computation. Gogel and Tietz examined a paradigm that has been well investigated in the perception literature and for which computational rationales have been developed. This paradigm was originated by Johannson (1975) in his studies of vector decomposition. As Rock (1983) has noted, this decomposition is functionally reasonable. If we are travelling on a train and waving our hands goodbye, it is the relative motion of the hands, not the absolute motion that is of significance. Waving goodbye carries the same meaning whether one is on a moving train or a stationary platform.

Gogel's work suggests that the observer has control over which framework is used in the vector decomposition. When two frameworks are available (Gogel & Tietz, 1976), the observer can choose which one to use. Similarly, the results of Gogel and McCracken suggest that an observer can choose to judge the absolute motion of a stimulus rather than its relative motion. Selection apparently allows us to decompose the same display in different ways. By studying attention within the framework of an established perceptual task, Gogel was able to assign an attentional effect to a particular computational stage. This in turn allows one to rationalize why that stage is attentionally coupled.

Gogel and Tietz write, "The large effect of voluntary attention upon the direction of the apparent path of motion of the test point in this experiment provides the clearest visual example known to the authors of the effect of attention on perception". One might question several aspects of the methodology: attention was controlled through instruction while several reviewers of this paper objected that oculomotor variables such as convergence and accommodation were not adequately controlled. However, the more important point is that this work apparently has not been considered part of the domain of studies relevant to the issue: how does attention affect stimulus processing. Although this study was published over ten years ago, it has not generally been cited in reviews of the early selection/late selection controversy.

There is a diverse literature on the effects of attention on perception that to a greater or lesser degree embodies the approach suggested in this paper. This literature includes studies of size and shape perception (Gogel, 1967; Epstein & Lovitts, 1985; Epstein & Broota, 1986), brightness and achromatic color perception (Coren, 1969; Festinger, Coren & Rivers, 1970; Brussell & Festinger, 1973; Brussell, 1973), motion perception (Dick, Ullman & Sagi, 1987), illusory contours (Pritchard & Warm, 1983), perception of length (Pressey, 1971; Pressey & Murray, 1976; Coren & Girgus, 1972; Coren & Porac, 1983; Girgus & Coren, 1982; Coren, 1986; Tsal, 1984; Riddoch & Humphreys, 1983; Jordan & Schiano, 1986), and perception of ambiguous figures (Tsal & Kolbet, 1985; Peterson, 1986; Hochberg & Peterson, 1987).

These studies vary in the success with which they isolate a particular computation and some suffer from poor control over attention or oculomotor variables. These studies also do not necessarily bear directly on whether recognition and memory access occur in parallel. For example, Biederman's (1987) theory of object recognition implies that effects of attention on quantitative aspects of shape such as length are irrelevant to recognition. However, the more important point is to deemphasize the distinction between early and late selection. Treisman's work on conjunctions (Treisman & Gelade, 1980), which sought to tie attentional effects to a particular computation has already shifted research away from the early/late dichotomy. However, Treisman's distinction between single features and conjunctions does not adequately summarize the range of computations involved in perception. Researchers should perhaps be skeptical of dichotomies such as early/late, singe feature/conjunction, or what/where.

It is increasingly clear that researchers in attention have only been partly successful in specifying the locus of attentional effects. One strategy for solving this problem is to embed attentional manipulations within perceptual paradigms that isolate particular computations.

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Acknowledgment

This work was supported by the Office of Naval Research, Contract N-0014-86-0269, and by the McDonnell Center for Higher Brain Function.

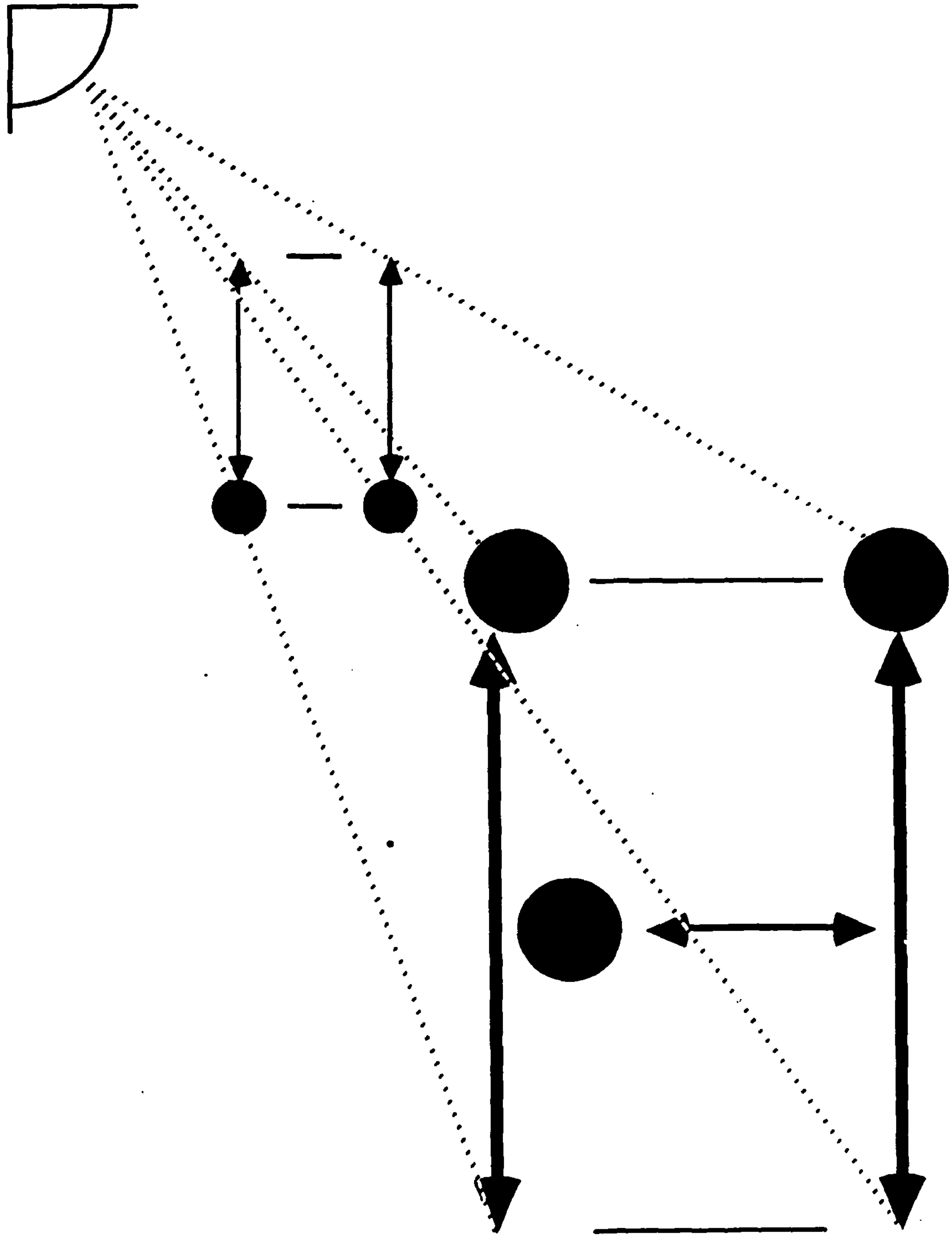
Footnotes

[1] Van der Heijden (1981) has noted that this controversy has collapsed two different issues: 1) what features can be analyzed in an initial stage of parallel analysis and 2) what features are used to select or transfer information to later capacity limited stages. Although theorists initially assumed that the answers to both questions were identical, recent theories have proposed that only certain features analyzed in the parallel stage can be used for efficient selection. Physical features may be more efficient for purposes of selection even though both physical and semantic properties can be analyzed in parallel. The question of which stimulus attributes are analyzed in parallel is therefore partly separate from the question of which stimulus attributes are used as a basis for selection.

[2] Some researchers have attempted to specify which processes are affected by attention by measuring whether d′ or beta are affected in different tasks by attentional manipulations (Muller & Findlay, 1987). Attentional effects on d′ are assumed to be 'perceptual' in nature, while effects on beta reflect later decision processes. This dichotomy is not very helpful. A large number of mechanisms can produce changes in d′. Also, the assumed relationship between signal detection parameters and internal mechanisms may be more complex than the usual dichotomy implies. While changes in beta are often ascribed to a single detection mechanism, the evidence for this is not compelling (Shulman & Posner, 1988). As Kahneman (1973) has noted, criterion shifts can have important 'perceptual' consequences.

Figure Caption

Figure 1. Context dots are placed at the near and far depth with test dot at the far depth (adapted from Gogel & Tietz, 1976).



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